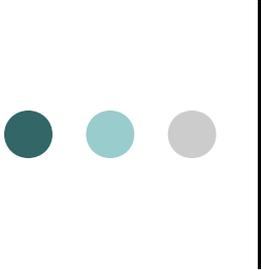


# Bridge Management System: an Italian Experience SAGGI

Fare clic per modificare lo stile del sottotitolo dello schema

*International Bridge Forum, Kings' College, Cambridge,  
UK, 13th-16th September 2009*

***Bridges 2020: Management for Long Term Bridge  
Performance***

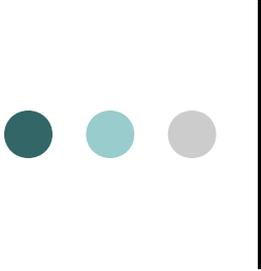


# Management

Management = continuous process that commences at the concept stage and applies throughout the key stages of the existence of any construction (i.e. bridge, building, tunnel,.....)

Key role represented by surveillance, monitoring and assessment

Goal = to know the conditions of structures, to predict their future behaviour and to assess their maintenance needs

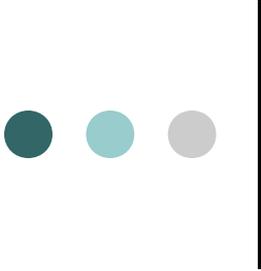


# For owners and operators

Economic Strategic Importance of themes such as:

- efficient inspections
- effective maintenance
- optimal management

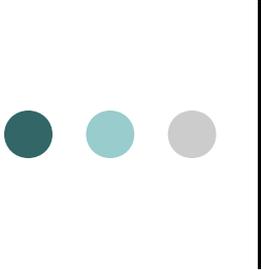
As time goes by and structures deteriorate and approach the end of their service life, these aspects, together with their associated costs, will progressively and relentlessly become more and more important with a large incidence on the budget of public and private owners and operators, thus **impacting either on taxation or on tolling**



# Problem

**Fundamental** = to develop solutions, technologies, processes and products aimed at:

- guaranteeing the safety of users
- increasing the durability of structures
- increasing safety against hazards (i.e. earthquakes)
- reducing maintenance and rehabilitation costs
- increasing transport capacity
- improving the safety of employees and workers



# Rules in Italy for surveillance of bridges and tunnels (1967)

## General Inspections

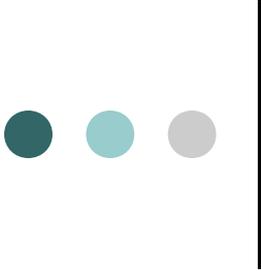
- Assessment of the conditions of all structures related to the infrastructure
  - every 3 month (technical personnel)
  - each year ( trained engineer)

total:1+4 = 5

## Report

- Inventory data
- Dates of inspection
- Names of the inspectors
- Results of the inspection
- Maintenance interventions (if any)

Notice: For railways the interval is 6 months



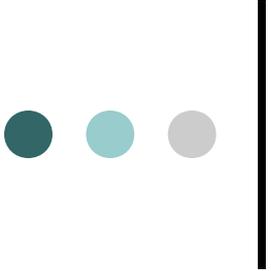
# Rules in Autostrade

General Inspections: STONE (1986)

- 3-month inspections
- ratings from 1 (good conditions) to 7 (bad conditions)

Principal Inspections: SAMOA-Surveillance, Monitoring and Maintenance of bridges

- every 1-2-5 years according to the state of deterioration
- defects (catalogue of 112 defects)
- 7 classes of deterioration



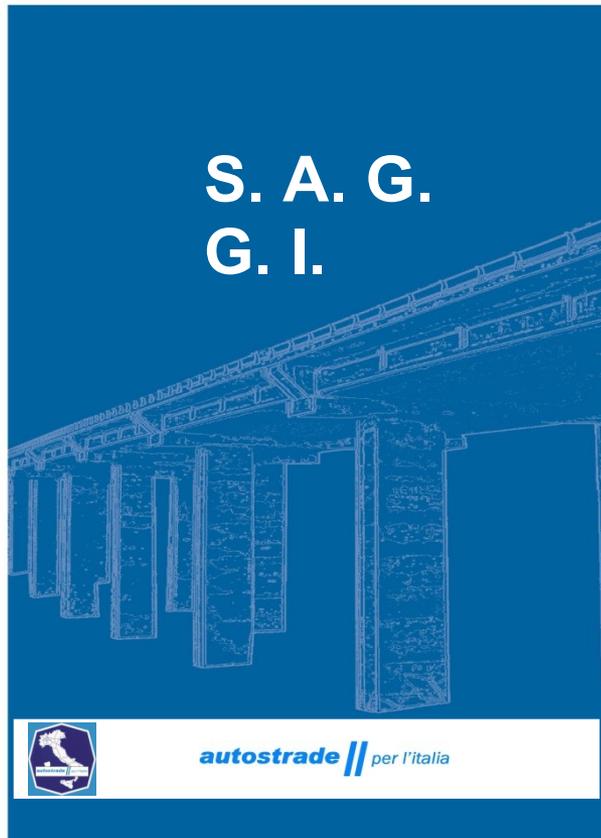
# Time to...

Re-thinking of the system (procedures and guidelines):

- inspecting and modeling of structures
- performance of structures in time in function of traffic loads
- performance of structures in time in function of seismic loads
- Decision Support System

While taking advantages of the developments in technologies and research

# S.A.G.G.I. - Advanced Systems for the Global Management of Infrastructures



The project aimed at developing an integrated bridge management system covering the different aspects of surveillance and assessment, allowing the treatment of both visual and instrumental data

The results of the projects represent a strong support to evaluate actual and future conditions of the network thus resulting in a more precise input for maintenance planning

**Research project financed by the Italian Ministry for Research (2005-2009)**

# General data

The screenshot shows the SAMOA web application interface. The sidebar on the left contains a tree view of categories: Archivi ausiliari, Anagrafico e morfologico (with sub-items like Scheda madre, Opera globale, Opera, Schede morfologiche previste, Elenco schede figlie, Scheda Fondazioni, Scheda Pile, Scheda Spalle, Scheda Archi, Scheda Impalcati, Scheda File Appoggio, Scheda Apparecchi Appoggio, Scheda Giunti, Scheda Attrezzature Giunti, Scheda Dispositivi Antisismici, Riepilogo quadro unione, Schede previste/inserite), Difetti (with sub-items like Scheda ispezioni, Fondazione, Pila, Spalla, Arco, Impalcato, Appoggio, Giunto, Reticoli), Interventi (with sub-items like Scheda interventi), Modifiche storiche, and Stampe.

The main content area displays the 'Inventory data' form for a specific work item. The form includes the following fields and values:

- Opera: 1606028200 VIADOTTO "BOSCO GRANDE"
- Autostrada: NAPOLI-CANOSA
- Tronco: TRONCO 6 CASSINO
- Tratta: NAPOLI-CANDELA
- Caposaldo SIC: [empty]
- Progr. Km: 52,732
- N° Opera Bis: [empty]
- Carreggiata: ENTRAMBE
- Progr. su strada da: 52,567
- a: 52,949
- Data Compilazione: 15-03-1986
- Tipo Sede: IN SEDE

The 'QUADRO D'UNIONE' section contains a table of coordinates:

COORDINATE			
Opera di rif.	X1	Y1	
1606028200	0,00	0,00	
	X2	Y2	
	19,10	0,00	

## Inventory data

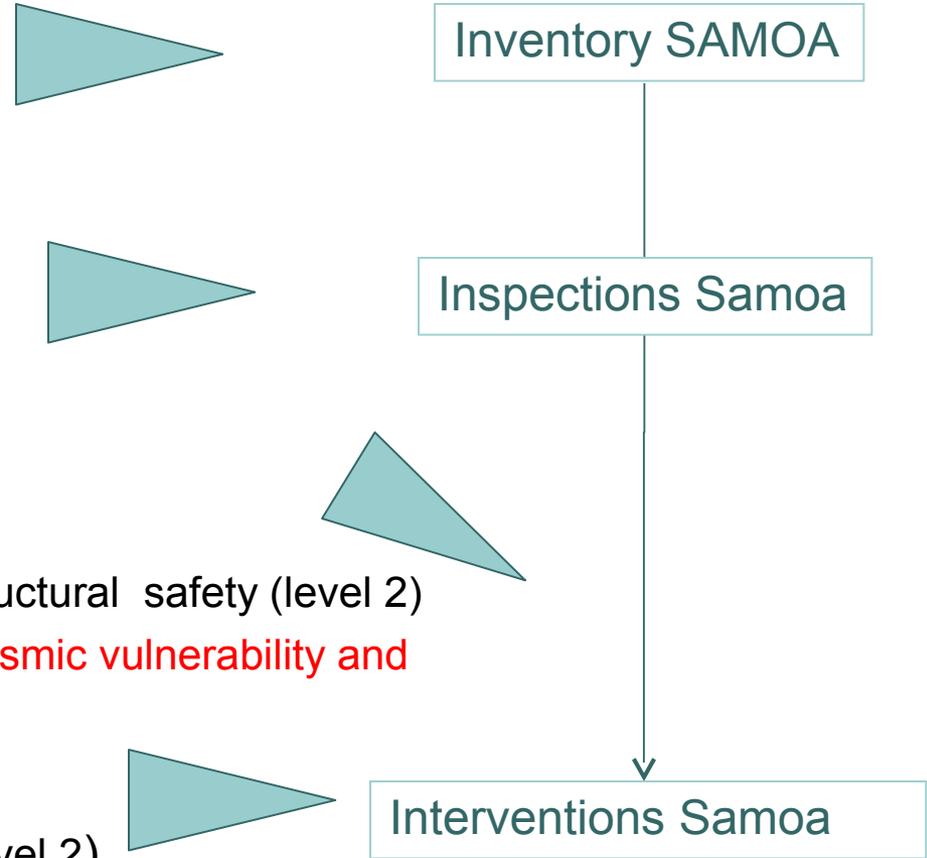
## Inspections

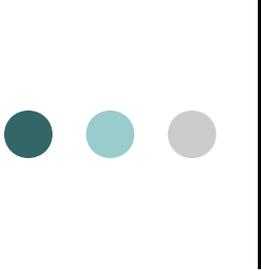
## Interventions

inventory data of the 3000 bridges and 1700 fly-overs inspections of more than 15 years

# Additional modules SAGGI

- Structural data
- Seismic (structural) data
- Inspections
  - 3 D inspections
  - Automatic recognition of defects
  - Porting of SAMOA on tablet PC
- State of the network
  - From visual data (level 0)
  - Algorithm for the evaluation of the structural safety (level 2)
  - Algorithm for the evaluation of the seismic vulnerability and risk (level 2)
- Decision Support System
  - Priorities of interventions (level 0 – level 2)



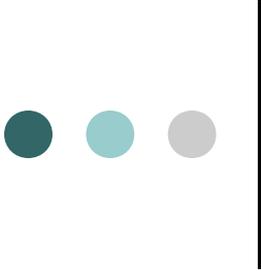


# Upgrading of visual inspections

Application of innovative technologies for the automation of visual bridge inspections, traditionally carried out by trained personnel

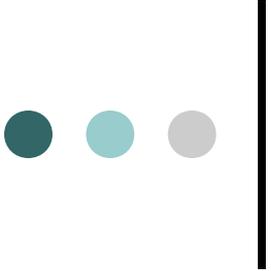
The proposed solution is based on :

- the use of a 3D laser scanner and a digital camera to quickly acquire a rich documentation of the surface of the structure to be analysed
- an automatic classifier of the scanner cloud points to identify the different morphological parts of the structure to relate the surface images to
- an expert system able to extract from laser scanner data different types of 2D images representing the surfaces of interest and to detect and classify specific deterioration
- a photorealistic 3D presentation of the status of the surface of the structure, linked to the Company's data base, as an aid for the maintenance staff



# Limits of the actual system

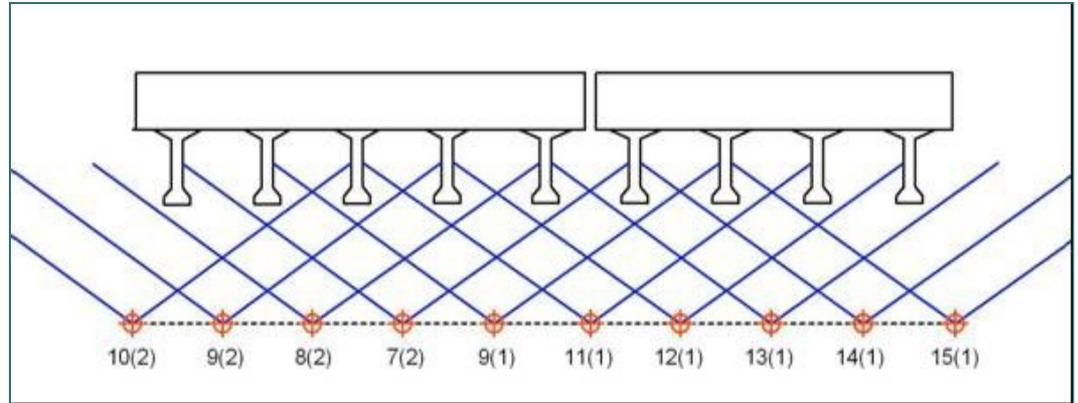
- Duration of inspections
- Impact on traffic
- Time to upload and transfer data
- Lack of automatization
- Interpretation of results
- Assessment of structures
- Costs



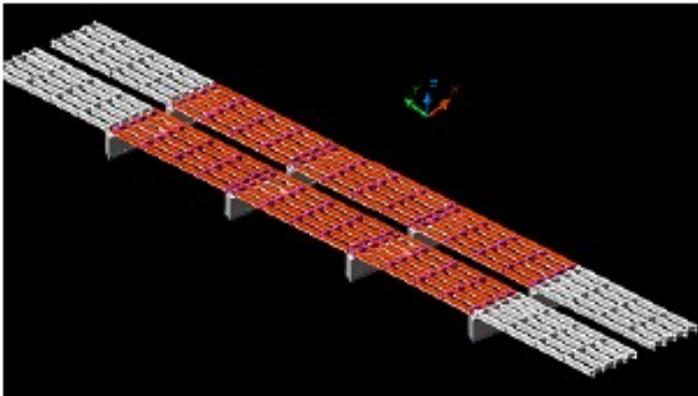
# Tested

- Different laser scanners (speed and resolution)
- Different cameras
- Different acquisition procedures
- Different laser parameters (reflectance)
- Other techniques: Thermography

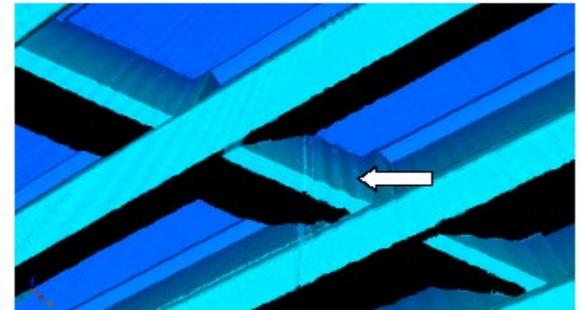
# Problems



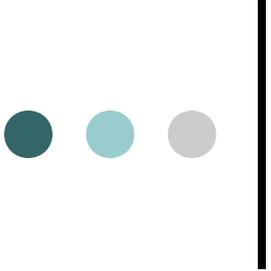
- Traffic induced vibration
- Wind
- Time for acquisition (scanning resolution)



1414



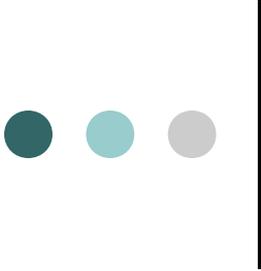
07/10/09



# Results

Target: <= actual inspection (2 hours)

Bridge	Type	Speed per scanning position +photos	Time per span (hours)	Post processing (hours)
Bridge 1	beams and cross beams	>30 min	>5	-----
		4 min	>2,5	>10
		150 sec no foto	2	3
Bridge 2	beams and cross beams	100 sec	2	3
		62 sec	0,45	1,5
Bridge 3	beams and cross beams	62 sec	1	1,5
Bridge 4	box girder	62 sec	10 min	1,5



# Automatic recognition of defects

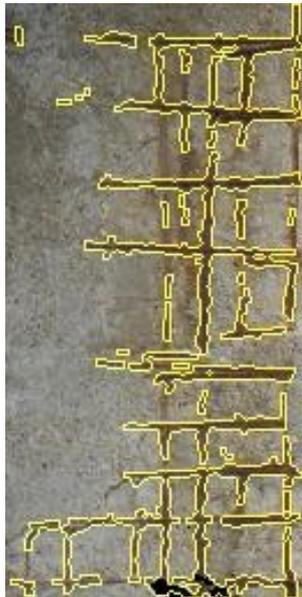
Automatic recognition of defects (approx. 50 out of 112)

Only concrete bridges (decks and piers)

- Reinforcement
- Prestressed reinforcement
- Concrete
- Cracking
- Water

# Reinforcement

Corroded reinforcement

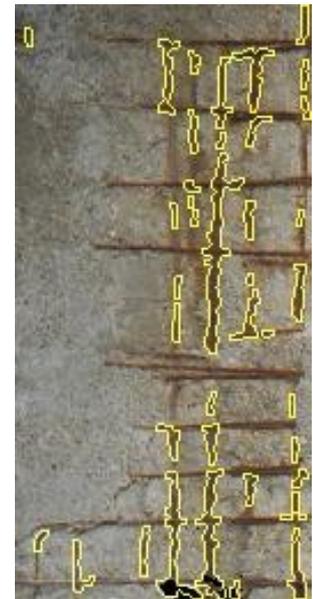


1717

Horizontal reinforcement  
(stir-ups)

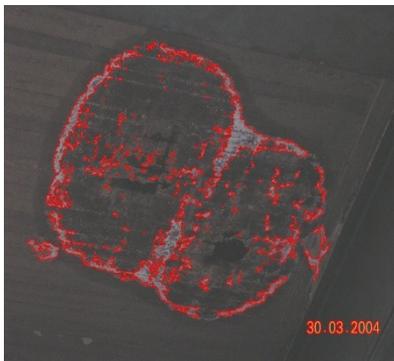


Vertical reinforcement



07/10/09

# Water



1818



07/10/09

# 2D 3D

**SCHEDA E3: DIFETTI IMPALCATI**

IMPALCATI A TRAVATA IN C.A.P. (Cavi accorciati) Carr. D Foglio n. 1

Codice opera \_\_\_\_\_ Data riv. \_\_\_\_\_

Numero elemento \_\_\_\_\_ Numero campata \_\_\_\_\_ Foglio n. \_\_\_\_\_  
 Numero travi \_\_\_\_\_  
 Numero trasversali \_\_\_\_\_

**TRAVI**

1	2	3	4	5	6
E					
D					
C					
B					
A					

**TRASVERSI**

1	2	3	4	5	6
6					
5					
4					
3					
2					
1					

**SOLETTA**

1	2	3	4	5	6
6F					
D					
C					
B					
A					
5F					

**CODICI DIFETTI TRAVI**

- Macchine di umidità
- Cia diastrot/ammalorato
- Vespai
- Armatura ordinaria scoperta/ossidata
- Lesioni in corrispondenza lesi di armatura scoperta/ossidata
- Riprese successive deteriorate
- Reazione chimica armatura di precompresioni
- Tessile di ancoraggio non sigillate
- Lesioni in corrispondenza di staffe
- Cilindro tamponi testate
- Lesioni da scoria lun-
- Umidità dall'esterno
- Cia diastrot/ammalorato testate
- Lesioni lungo suda del tubo
- Quarne in vista
- Quarne degradate e fissate
- Oggragione esterna.
- Tracce di scolo
- Staffe scoperte/ossidate
- Lesioni in corrispondenza lesi di armatura scoperta/ossidata
- Riprese successive deteriorate
- Reazione chimica armatura di precompresioni
- Lesioni longitudinali non sigillate
- Danni da urto
- Umidità dall'esterno
- Cia diastrot/ammalorato testate
- Lesioni diagonali
- Lesioni in corrispondenza travi - trasversali
- Staffe scoperte/ossidate testate
- Lesioni in corrispondenza lesi di armatura scoperta/ossidata
- Quarne in vista
- Quarne degradate e fissate
- Oggragione esterna.
- Fuoriuscita barre ancoraggio

**CODICI DIFETTI TRASVERSI**

- Macchine di umidità
- Cia diastrot/ammalorato
- Vespai
- Armatura ordinaria scoperta/ossidata
- Lesioni in corrispondenza di staffe
- Tessile di ancoraggio non sigillate
- Lesioni verticali
- Lesioni diagonali
- Lesioni in corrispondenza travi - trasversali
- Staffe scoperte/ossidate testate
- Lesioni in corrispondenza lesi di armatura scoperta/ossidata
- Quarne in vista
- Quarne degradate e fissate
- Oggragione esterna.
- Fuoriuscita barre ancoraggio

**CODICI DIFETTI SOLETTA**

- Macchine di umidità
- Cia diastrot/ammalorato
- Vespai
- Armatura ordinaria scoperta/ossidata
- Lesioni in corrispondenza di staffe
- Tessile di ancoraggio non sigillate
- Lesioni diagonali
- Efflorescenze
- Lesioni longitudinali
- Lesioni in corrispondenza lesi di armatura scoperta/ossidata
- Lesioni trasversali
- Lesioni attacco trave-soletta
- Fuoriuscita barre ancoraggio

SAMOA - Sorveglianza, Auscultazione, Manutenzione delle Opere d'Arte - Microsoft Internet Explorer

Reticoli Scheda Difetti E3 - IMPALCATI A TRAVATA IN C.A.P. (CAVI SC.)

Clicca qui per visualizzare la scheda relativa.

Opera: E30009200 VIADOTTO "SALLE"  
 Carr.: 0 - Completata il: 24-11-2004  
 N°Campata: 1

Elementi interessati

Tipi	N°Segg.	Tipi Reticolo	Righe	Colonne
E	11	SOLETTA IMPALCATI A TRAVATA	5	4
		TRASVERSI	4	4
		TRAVI	3	3

TRAVI

	1	2	3
C	108-A	2-A	108-A
2-A			109-A
			2-A
			21-A
			4-A
			5-A
B	11-A	2-A	2-B
			24-B
			4-B
			4-B
			5-B
A	2-A	2-A	108-A
			2-A
			21-A
			4-B
			5-A

Non Esistente  
 Non Visibile  
 Codice Normale

SAMOA OVEST - Alberto Ascendi - Microsoft Internet Explorer

Samoa Ovest

Parametri generali di ricerca

Ultimi parametri di ricerca

Elementi scelti

Opzioni di visualizzazione

Data di ispezione: 22/10/2007

Visualizza etichette

Scheda difetti



1919

07/10/09

# New Format

The screenshot displays the SAGGI software interface for a viaduct project. The main window is titled "SAGGI - Viadotto su torrente carapelle". It features a 3D model of the viaduct structure on the left, with a toolbar below it containing icons for "Wireframe", "Textures", "Difetti", and "Gravità". To the right of the 3D model is a data entry panel with the following fields:

- Opera: 1408252301 VIADOTTO SU TORRENTE CARAPELLE
- Autstrada: BOLOGNA-TARANTO
- Tronco: TRONCO 8 BARI
- Tratta: POGGIO IMPERIALE - BARI
- Data Inizio Ispezione: 26/03/2008
- Data Fine Ispezione: 26/03/2008

Below the data entry panel is a tree view titled "Ispezione 17-05-2001" showing a hierarchical structure of the viaduct components:

- Campata 1
  - Fondazione 1
  - Fondazione 2
  - Pila 1
    - ARCHITRAVE (highlighted)
    - ELEMENTO VERTICALE
  - Spalla 1
  - Impalcato 1
  - Fila di appoggi 1
  - Giunto 1
  - Giunto 2
- Campata 2
- Campata 3
- Campata 4

To the right of the tree view is a "Reticoli Scheda Difetti B - PILE" section, which includes a "Click qui per visualizzare la scheda relativi" link and a table for "ELEMENTI INTERESSATI" and "Tipo Reticolo".

ELEMENTI INTERESSATI		Tipo Reticolo		
Type	N°Pila	Reticolo	Altezza	Colonna
ARCHITRAVE		1	A	
ELEMENTO VERTICALE		3	B	

ARCHITRAVE			
1	2	3	4
2-A	14-A	2-A	
11-A	2-A	11-A	
9-A	11-A	14-A	11-B
		9-A	

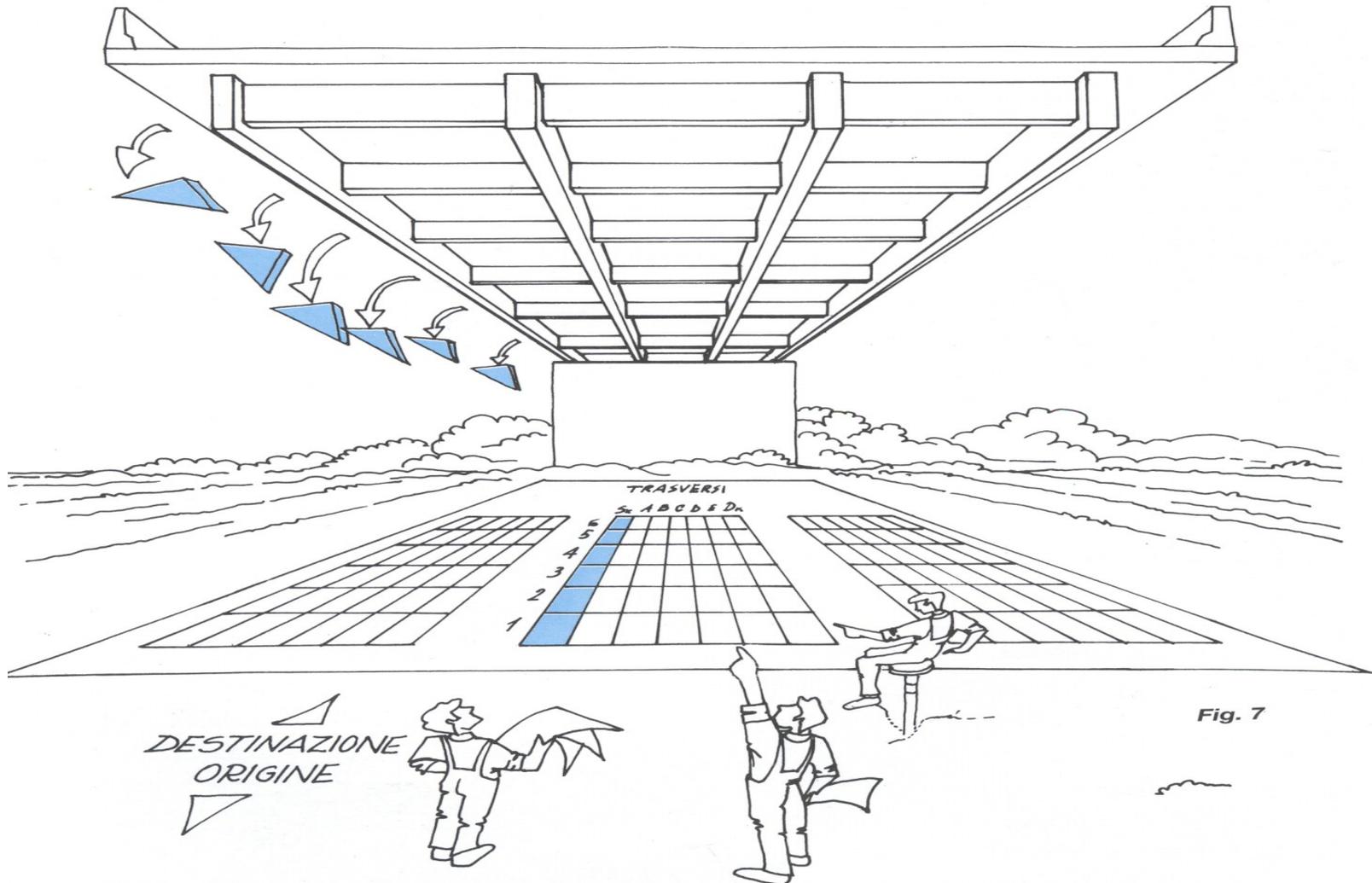
Legend:  Non Esistente,  Non Visibile,  Corrente Normale

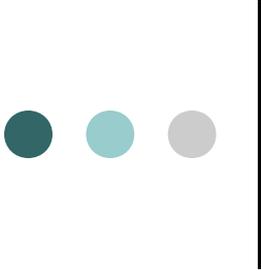
- Web based
- Possibility of rotating, translating, zooming the 3D model
- Possibility of visualizing all the smallest elements of the structure
- Possibility of visualizing the defects both on the 3D model and on the old format

2020

07/10/09

# Discretization of the structure





# Further topics to be explored

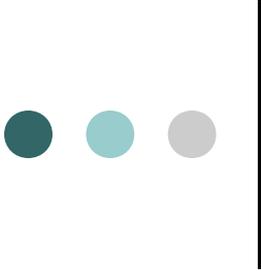
## Acquisition of the geometry

- Improve the speed of data processing (hardware and software)
- Improve speed of on-site operations: development of a robotic arm mounted on a truck

## Automatic recognition of defects

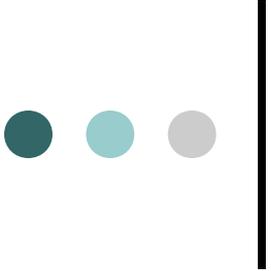
- Validate and calibrate the procedure (defects)
- (Extend the procedure to other structural parts and defects)
- Improve speed of data processing
- Improve the web page

**In two-year time**



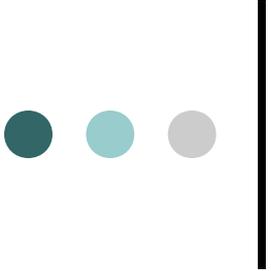
# Evaluation of the seismic behaviour

- Assessment of bridge conditions and understanding of their behaviour, in function of deterioration, both under service loads and in case of earthquakes
- Corrosion of reinforcement = main cause of deterioration
- Consequences = Reduced service life  
Need for maintenance interventions
- Assessment of both theoretical and numerical models, validated by laboratory tests on large-scale beams, artificially corroded, to assess the structural relevance of deterioration and to evaluate the residual load-carrying capacity of bridges.
- Predictive models = the input of the assessment of seismic risk



# Problem

- Many existing bridges designed without adequate consideration of the seismic risk
- The seismic zonation map in Italy has been revised recently, prescribing more severe peak ground accelerations in several regions
- Reliable methods for assessing the seismic vulnerability of existing bridges were needed



# Approach

In the project two different approaches for the assessment of seismic risk were developed:

- **Level 0.** The first approach is based on the assignment of proper ratings to different characteristics of each structural element (piers, abutments, bearing devices, etc.).

Goal = It mainly aimed at prioritizing and screening operations

- **Level 2.** The second approach is based on the use of Fragility Curves, associated to different performance levels of the bridge, and then combined with a representation of the seismic hazard of the site.

Goal = It mainly addressed to an accurate assessment of the seismic risk of the bridge

# Proposed procedure (level 2)

**V.R.S. - Bridges**

**NEW PROJECT**

**Vulnerability and Seismic Risk Assessment of Highway Bridges**

**Authors:**  
Ing. G. Perrone  
Ing. D. Cardone  
Prof. Ing. M. Dolce

**INFO** **FLUX DIAGRAM**  
**HELP** **EXIT**

1. <b>GENERAL Data</b> <b>OK</b>	6. <b>PIERS Properties</b> <b>OK</b>
2. <b>MASS Data</b> <b>OK</b>	7. <b>BEARINGS Properties</b> <b>OK</b>
3. <b>PIERS Data</b> <b>OK</b>	8. <b>PIERS F-d Diagrams</b> <b>OK</b>
4. <b>BEARINGS Data</b> <b>OK</b>	9. <b>LONGITUDINAL PUSHOVER</b> <b>OK</b>
5. <b>DECKS Data</b> <b>OK</b>	10. <b>TRANSVERSAL PUSHOVER</b> <b>OK</b>

**GRAPHICS AND NUMERICAL OUTPUT DATA**

<b>PIERS Graphics</b> <b>OK</b>	<b>Longitudinal Fragility Curves</b> <b>OK</b>
<b>Longitudinal Graphics</b> <b>OK</b>	<b>Transversal Fragility Curves</b> <b>OK</b>
<b>Transversal Graphics</b> <b>OK</b>	<b>Longitudinal ADRS</b> <b>OK</b>
<b>Select PL</b> <b>OK</b>	<b>Transversal ADRS</b> <b>OK</b>

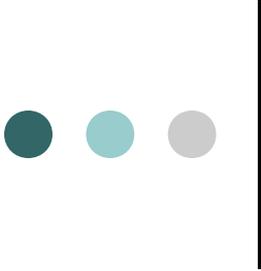
**FINAL RESULTS**

11. <b>Vulnerability</b> <b>OK</b>	12. <b>Seismic Risk</b> <b>OK</b>
------------------------------------	-----------------------------------

**SEISMIC RETROFIT MEASURES**

<b>PIER JACKETING</b> <b>OK</b>	<b>ISOLATION</b> <b>NO</b>
---------------------------------	----------------------------

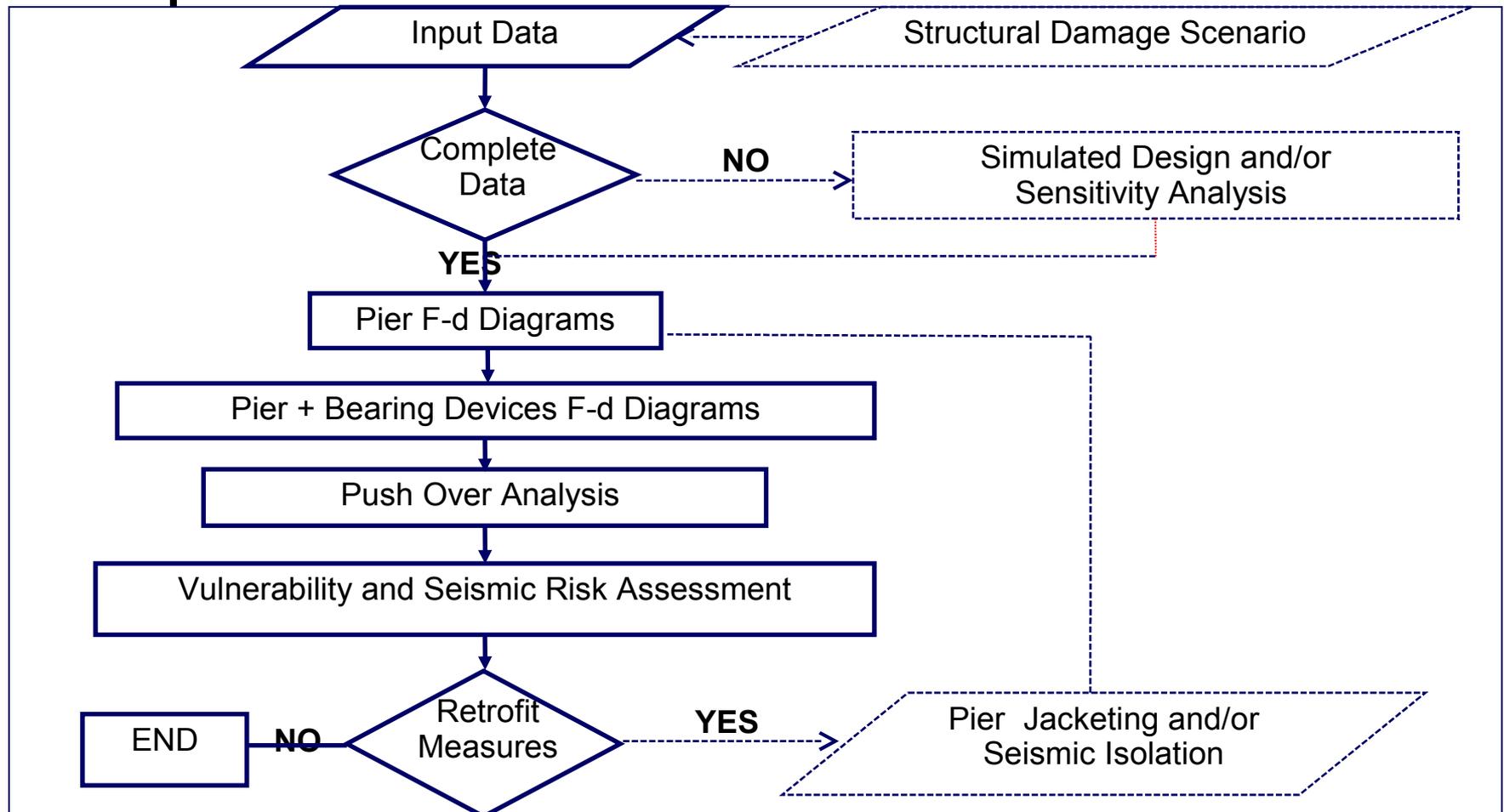
Programma / Diagramma di Flusso / INPUT / MASSE / PILE / PILE FIN / MOM FIN / APPOGGI / IMPALCATI / Livelli PILE / Livelli APPOGGI / Caratteristiche Pile / Mom\_curv\_trasv / Mom\_curv\_long / Aux



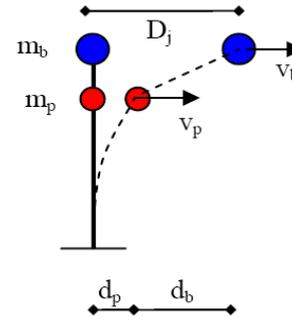
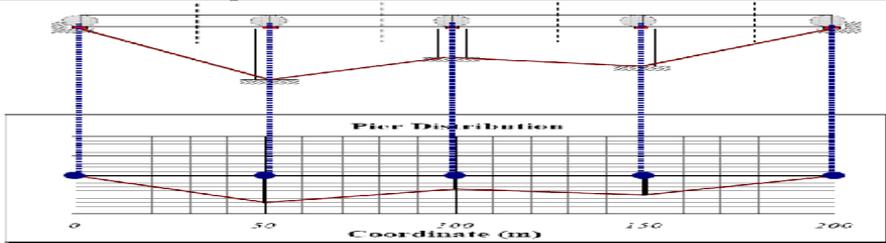
# Evaluation of seismic behavior

- Detailed Input Data of the bridge structure (structural types of decks, piers, pier-deck connections and bearing devices)
- Adaptive Pushover Analysis for the characterization of the seismic resistance of the structure
- Seismic vulnerability expressed through fragility curves (i.e.  $P(DS>PL)$  vs. PGA) associated to selected performance levels
- Seismic risk obtained from hazard maps combined with fragility curves
- Ability to operate for different performance levels
- Possibility to account for different damage scenarios and/or retrofit measures

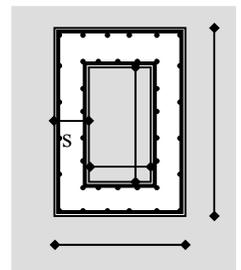
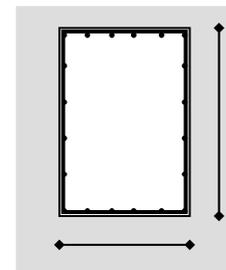
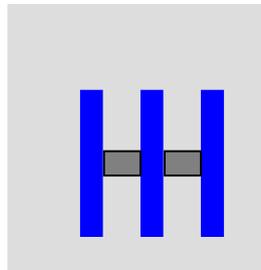
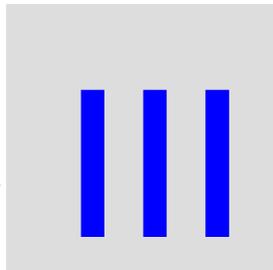
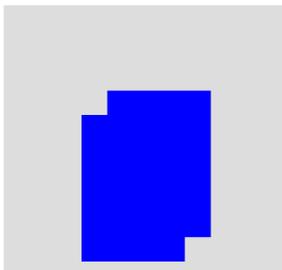
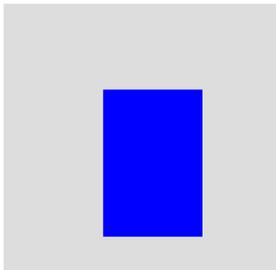
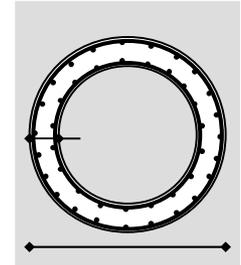
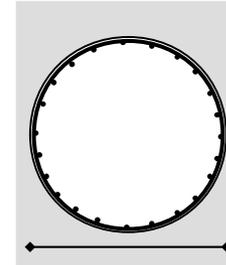
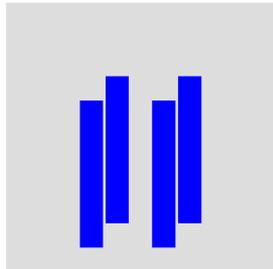
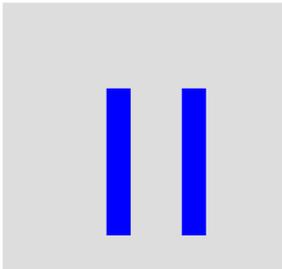
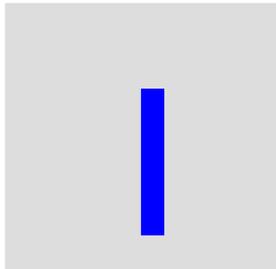
# Basic steps of the procedure



# Input data (1/2)

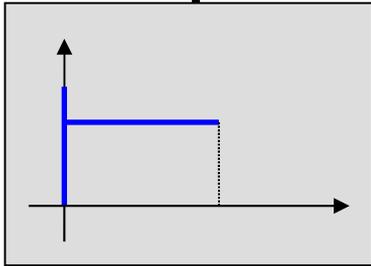


Input data (1/2):  
 Bridge geometry,  
 Masses, Resp.  
 Spectrum

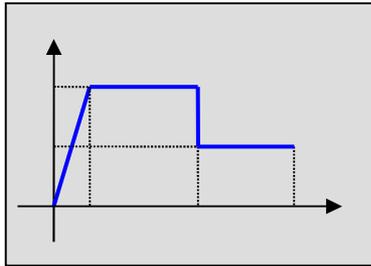


Input data (2/2): Pier Types, Materials, Reinforcement, Structural Decay

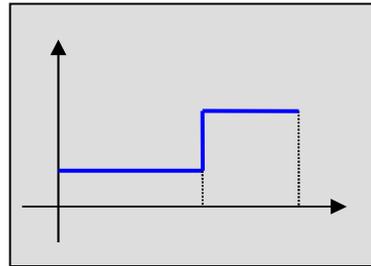
# Input data (2/2)



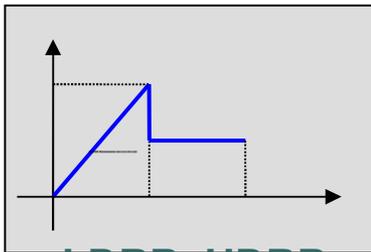
Steel Hinges



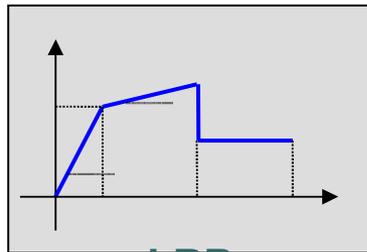
Neoprene Pads



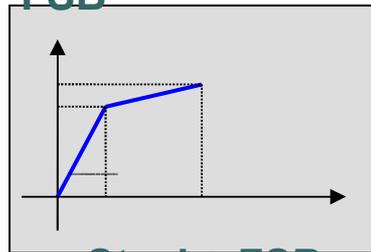
Steel Rollers, RC/steel pendulum, steel-PTFE FSB



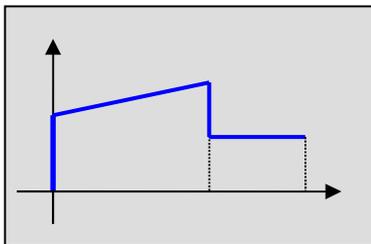
LDRB, HDRB



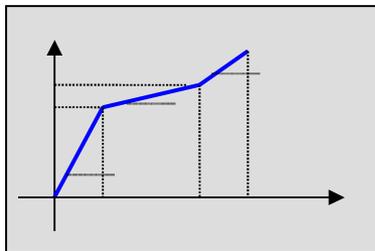
LRB



Steel + FSB



FPS 3030



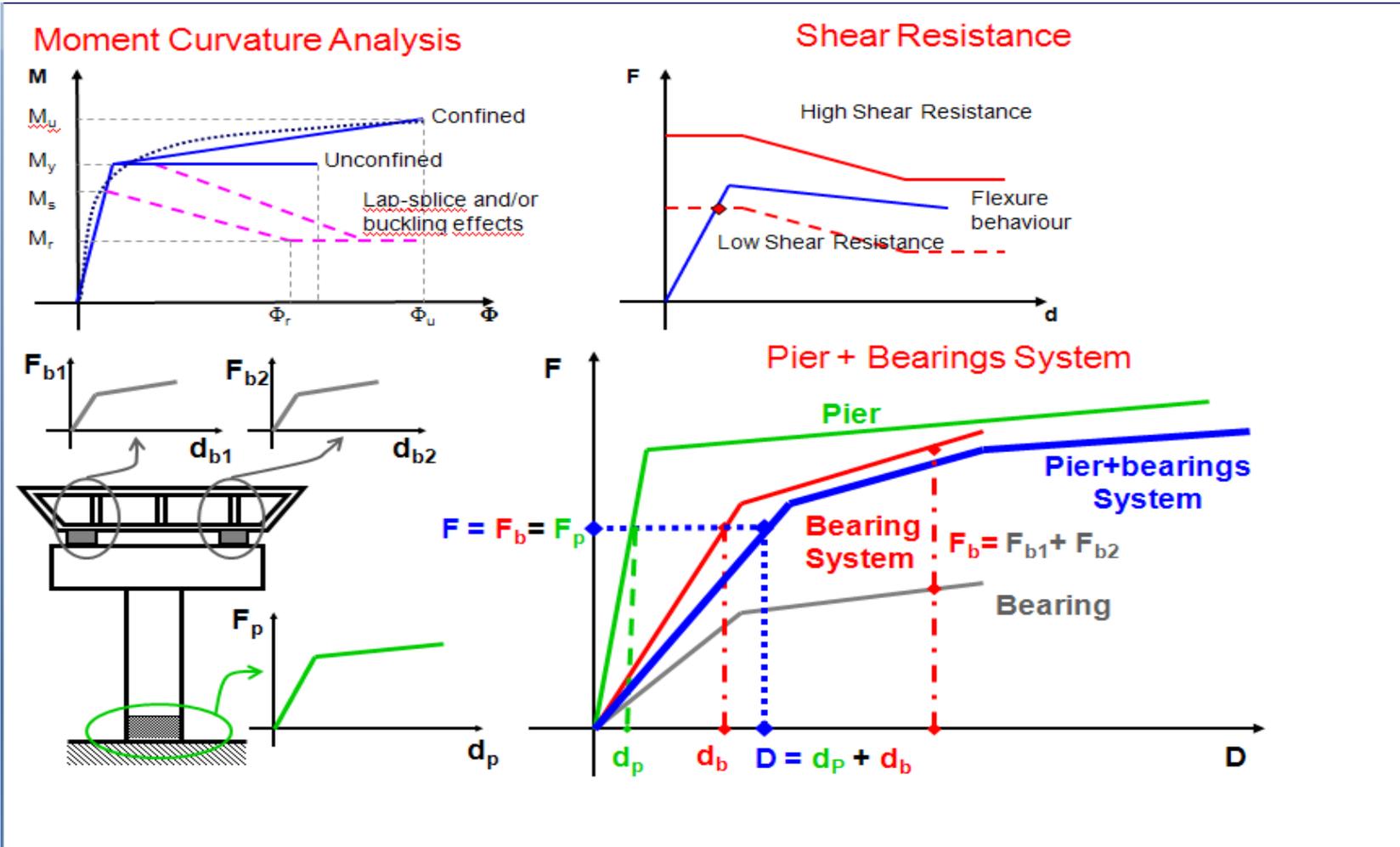
SMA + FSB

Bearings

Isolation Systems

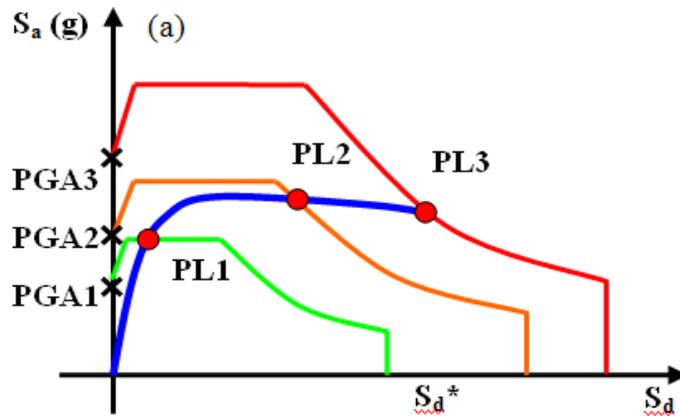
07/10/09

# Definition of the mechanical behaviour of piers and bearings

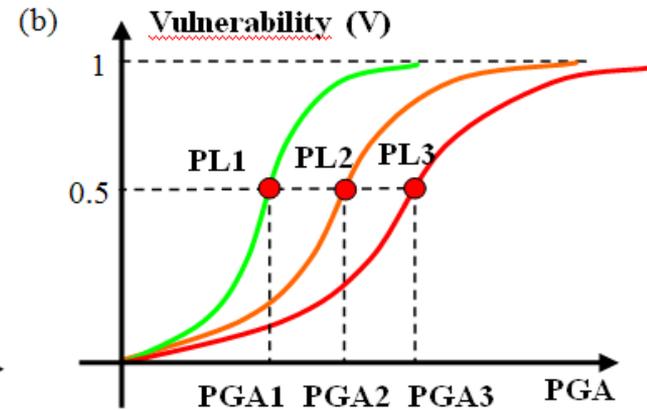


# Evaluation of vulnerability and seismic risk

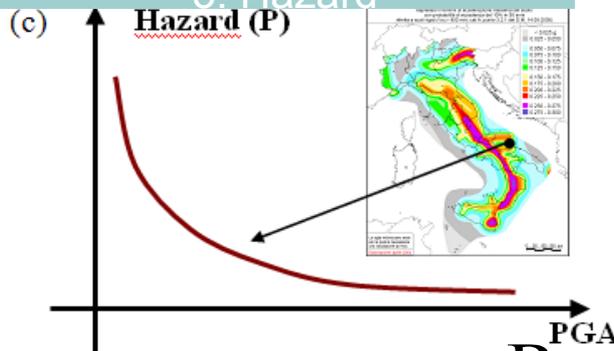
## 1. Definition of PGA & L.P.



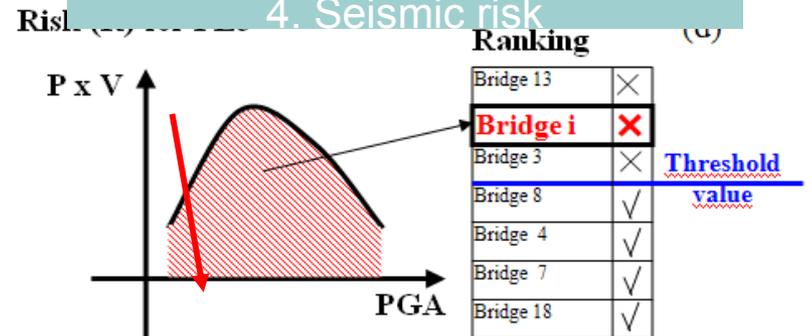
## 2. Fragility curves



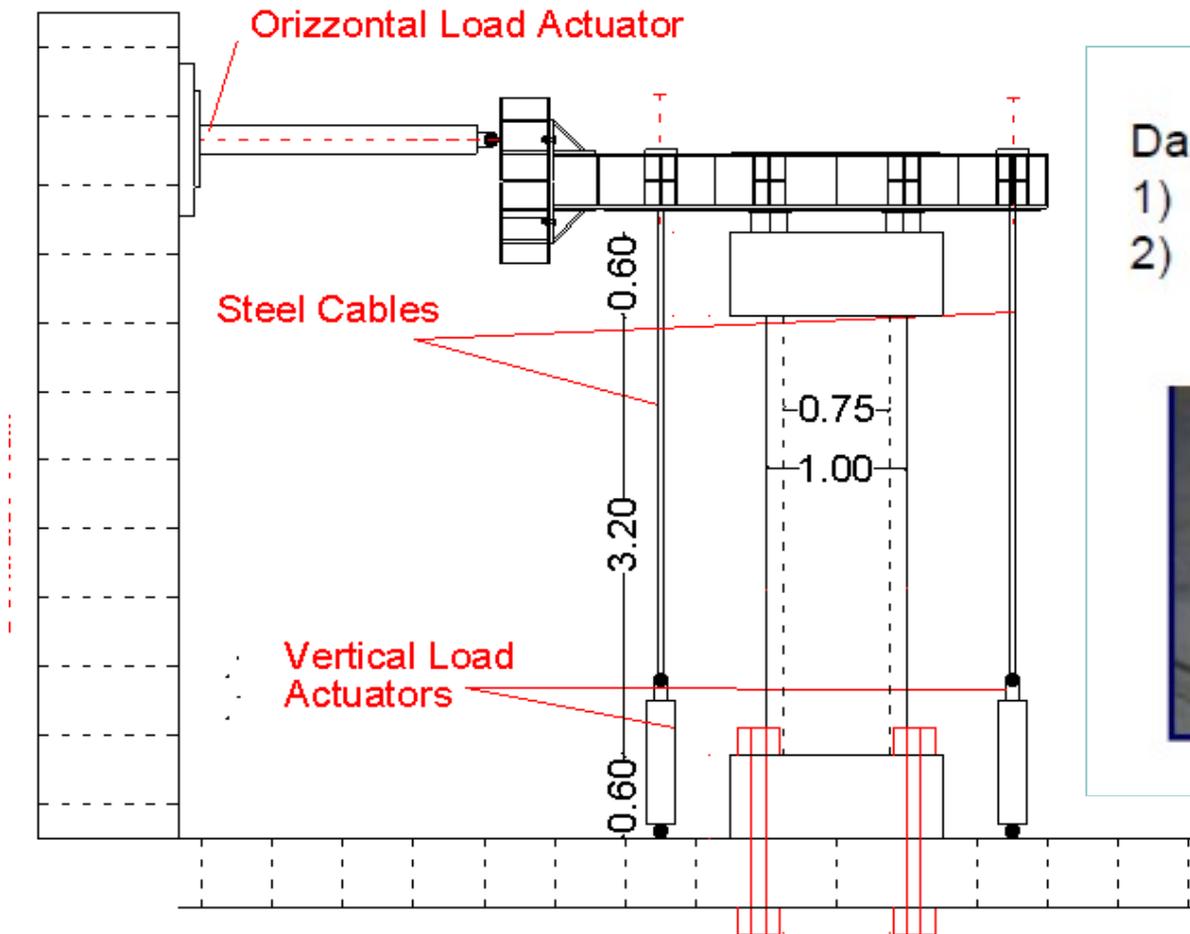
## 3. Hazard



## 4. Seismic risk



# Testing layout: pier+bearing

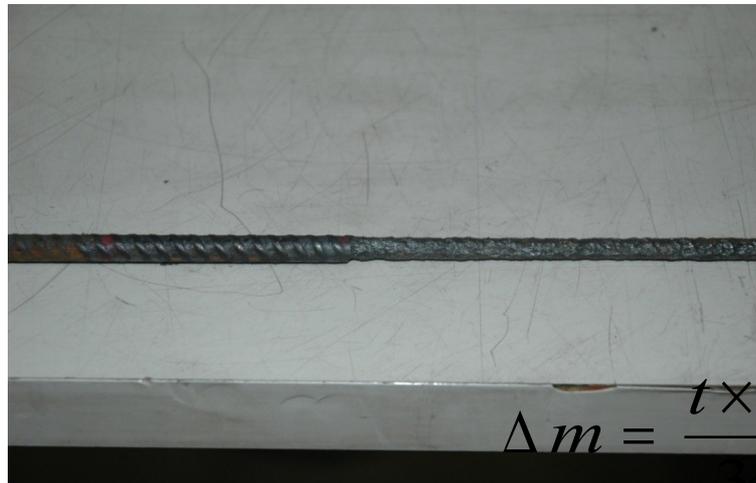
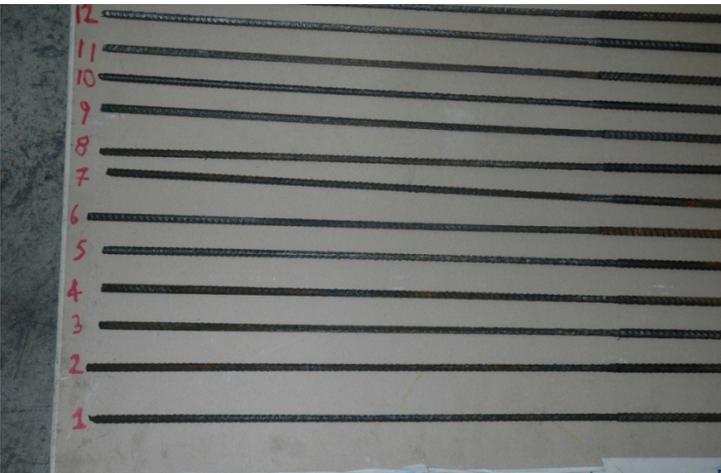


## Damage

- 1) Corroded rebars
- 2) Real (used) bearings

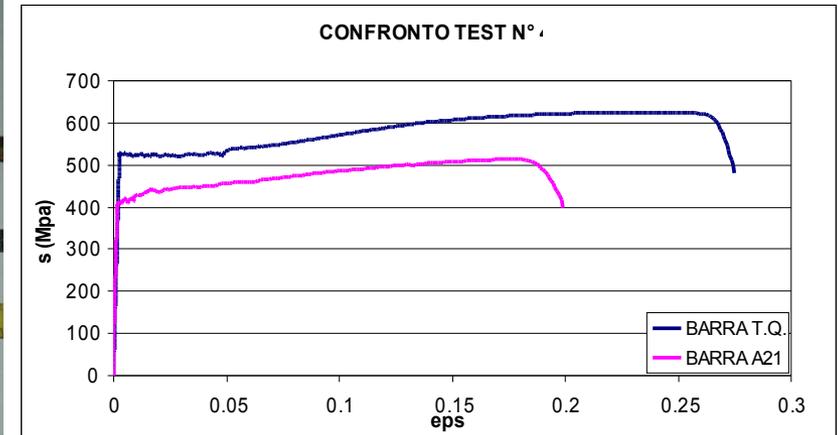
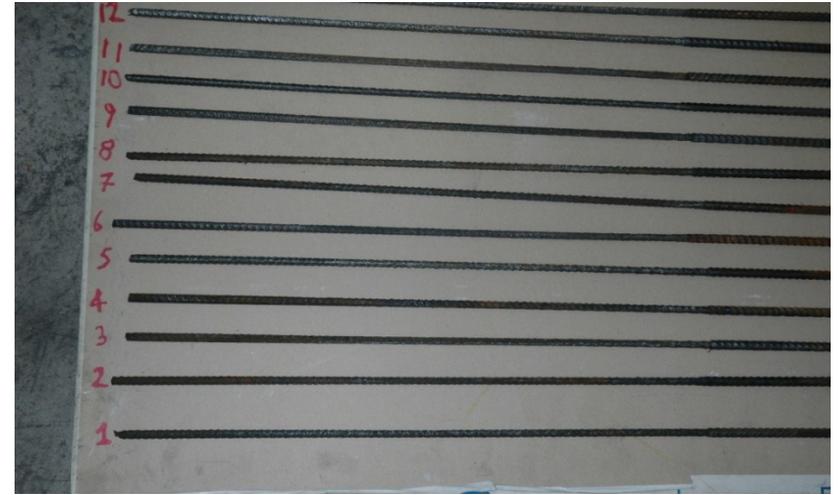


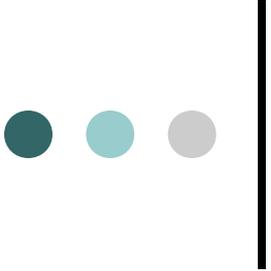
# Deterioration process of rebars (1/2)



$$\Delta m = \frac{t \times I_{corr}}{5446}$$

# Deterioration process of rebars (2/2)



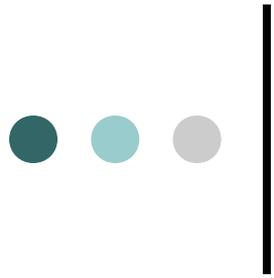


# Further topics to be explored

Analytical and experimental investigation of critical bridge components (piers, bearings), under different decay conditions, with a view to improved design procedures and/or effective retrofit measurements

Experimental assessment, quality control and acceptance of bridge bearings under static and dynamic loading (testing campaign on existing bearings)

Calibration and validation of results (ratings from visual inspections)



Thank you for your attention

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3737